Quarterly Report No. 2

King County
Fuel Cell Demonstration Project

Quarter 4, 2004

Prepared for

US EPA

April 2005

Prepared by

King County

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and

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Background

This Quarterly Report for the King County Fuel Cell Demonstration Project is intended to provide information regarding the experience gained from the operation of the fuel cell as well as performance data. This is the second Quarterly Report. The first Quarterly Report covered quarters three and four, 2005. The Quarterly Reports will be submitted throughout the two-year demonstration period, April 2004 – April 2006. The demonstration period has two objectives:

(1) That molten carbonate fuel cell technology can be adapted to use anaerobic digester gas as a fuel source; and
(2) That a nominal plant power output target of 1 MW (net A.C.) can be achieved using either digester gas or natural gas/scrubbed digester gas.

The participants in this project are:

- King County
- FuelCell Energy Inc.
- U.S. Environmental Protection Agency (EPA)
- CH2M HILL
- Brown and Caldwell
- Hawk Mechanical

In cooperation with the U.S. Environmental Protection Agency (US EPA) and FuelCell Energy Inc., King County is sponsoring the world's largest demonstration project of a molten carbonate fuel cell (MCFC) (1 mega watt (MW)) using digester gas. CH2M Hill and Brown and Caldwell are assisting King County in the coordination and management of the overall project. CH2M HILL and Brown and Caldwell have direct responsibility for monitoring and reporting of project status, design and utility interface requirements, assistance during construction, start-up, testing, and operation, and analysis and reporting of the results of the demonstration project.

The King County demonstration plant is sized to produce 1 MW of power. A significant portion of the waste heat from the fuel cell power plant exhaust will be integrated into the existing heat distribution system at the treatment plant offering further efficiency. MCFC is one of the most efficient of the fuel cell technologies under development. Fuel cells produce electric power directly through electrochemical reactions using air and fuels such as natural gas, landfill gas, and anaerobic digester gas. By avoiding the two step process of conventional combustion technology, where fuel is first burned and then heat is used to produce power, fuel cells are most energy efficient, better for the environment, quieter, and ultimately more cost effective.

Review of Fuel Cell Performance

The fuel cell began start-up in April 2004 and official operation in June 2004. This report covers Quarter 4 (Q4-04), 2004.

Q4-04 was a transition phase for the fuel cell from natural gas to digester gas. During the end of Q3-04, King County had a planned 3-week electrical plant shutdown. At that time, the logic of the fuel cell was modified to allow a fuel switch, while running at full power (plant load), from digester gas to natural gas. This change in logic was in response to frequent digester gas British Thermal Unit (BTU) content variation caused by recycling natural gas into the digester gas system during times when the natural gas that was to be sold to Puget Sound Energy (PSE) did not meet the required gas pressure specification and was diverted from the PSE gas pipeline and recycled back into the gas system. This is referred to as a "divert." The fuel switch logic was tested during most of Q4-04 and testing was complete by mid December. Once the logic changes were implemented, the fuel cell operated at plant load (1 MW) for the remainder of Q4-04.

Description of Three Gas Supplies

There are three gas supplies to the fuel cell:

- **Gas 1** = Natural Gas from King County (KC) – Anaerobic digester gas from KC that has been scrubbed on-site to "pipeline quality" natural gas
- **Gas 2** = Natural Gas from Puget Sound Energy (PSE) – Natural gas supplied by the local gas utility, PSE
- **Gas 3** = Raw Digester Gas – unscrubbed anaerobic digester gas from the digester gas scrubber header

The target net energy output from the fuel cell is 1MW of AC power. An input flow of approximately 147 cubic feet per minute (cfm) is required from gases 1 and 2 to achieve this output, while approximately 227 cfm is required from gas 3 to achieve this output.

Major Activities During Reporting Period

The first three weeks of this quarter were a continuation of a planned plant shutdown not related to the fuel cell project. FCE took advantage of this down time to modify the control logic such that the gas supply to the fuel cell stack can be switched without an interruption in power generation from the fuel cell, as described above. The plant shutdown extended beyond the original planned date as FCE unexpectedly had to replace the fuel cell preconverter due to a plant problem that occurred in the days prior to the shutdown.

Due to the numerous diverts that occur at the South Plant, and the impact that this has on digester gas operation, FCE developed new logic to allow continued operation on digester gas. This logic allows the fuel cell plant to transition automatically from digester gas operations to natural gas operations. The control logic was tested and modified the last week in October through December 16th, with a one week break at the end of November for the Thanksgiving holiday. The logic required more modifications and time than had been anticipated. The time was well spent as improved availability and capacity factors will be achieved.

Once the logic testing was complete, the fuel cell generated full power (1MW net output), continuously for all but 10.5 hours, from December 16th through the end of the quarter. This included eight continuous days of full power generation on digester gas supply (gas 3).

Because of the high levels of carbonyl sulfide (COS) found in the natural gas from PSE, planning and construction of a new, permanent cold gas desulfurizer vessel dedicated to carbonyl sulfide (COS) removal started in the third quarter (Q3-04). At the end of the fourth quarter construction of the new COS vessel was substantially complete. The concrete pad was installed, the pipe to the vessel was installed, and the vessel was delivered to the job site.

Classroom training for operators and for maintenance personnel was also completed during this quarter. Ten operators and five others completed the operator training, and eleven personnel from maintenance completed the preventative maintenance training.

Efficiency Calculations

Efficiency is calculated in seven ways as shown in Table 1. The basic efficiency reported for the power plant on natural gas includes plant parasitic power as well as the DC to AC conversion losses. Calculations show an efficiency range of 41-45% while operating on natural gas (Efficiency Measurement 1), and 44-45% while operating on digester gas, including the digester gas skid load losses (Efficiency Measurement 2), and 46-47% without those loads (Efficiency Measurement 3).

Table 1 – Efficiency Calculations

Efficiency Measurement	Components	Where Calculated on Flow Chart	How Calculated
1	Power plant system on natural gas	C/A	Electricity out /Total fuel in (natural gas)
2	Power plant system on digester gas	C/(A+B)	Electricity out /Total fuel in (natural gas for pilot light + digester gas)
3	Power plant system on digester gas (with digester gas skid losses)	(C+F)/(A+B)	(Electricity out +power used for skid)/Total fuel in (natural gas for pilot light + digester gas)
4	Fuel stack only	G/I	Measurement method to be determined
5	With heat recovery on natural gas	(C+D)/A	(Electricity out + heat energy recovered)/Total fuel in (natural gas)

Efficiency Measurement	Components	Where Calculated on Flow Chart	How Calculated
6	With heat recovery on digester gas	(C +D)/(A+B)	(Electricity out + heat energy recovered)/Total fuel in (natural gas for pilot light + digester gas)
7	With heat recovery on digester gas (with digester gas skid losses)	(C+F+D)/(A+B)	(Electricity out +power used for skid + heat energy recovered)/Total fuel in

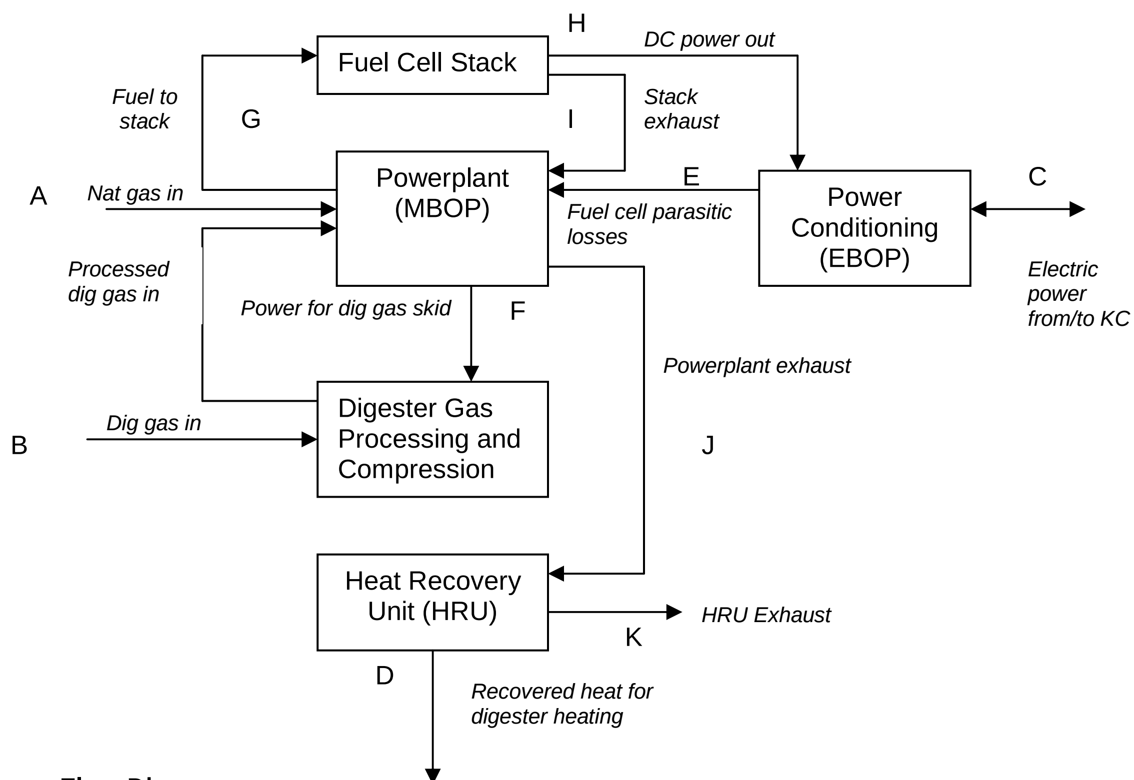

Figure 1 – Process Flow Diagram

Highly accurate efficiency calculations require use of flow meters calibrated to greater accuracy than the meters at the fuel cell power plant. Therefore, efficiency numbers will differ depending on the method used to obtain gas flow information and electrical output data. The efficiency calculations presented here have an estimated +/- 2 to 3% variance.

Graphical results from efficiency measurements 1 and 2 are shown in Appendix A. These measurements come from logging devices in the fuel cell power plant. A handheld clamp-on ammeter was used to calculate the power draw to the digester skid. Only one spot measurement was taken this quarter, on December 11. The power draw was 43 kW.

All efficiency calculations are based on the fuel lower heating value (LHV) of 900 BTU/ft3 for natural gas and 548 BTU/ft3 for digester gas. The efficiency calculations are done at full load under standard conditions. Variations in ambient temperature and elevation do impact the fuel cell performance and efficiency. There has been some tuning of equipment on-site to reduce parasitic loads.

The heat recovery unit (HRU) is currently not fully operational. Efficiency Measurements 5, 6 and 7 will be completed once the HRU is in operation.

Operational Summary

One measure of the fuel cell's performance is availability, or the percentage of time the fuel cell operates relative to the amount of time it is available to operate. For this quarter, the operation time was evaluated from November 24th through December 1st, and from December 16th through December 31st. The times it was unavailable were due to KC construction needs and FCE testing of the logic changes to support switching fuels at power.

During Q4-04 the fuel cell operated most of the time it was available to operate. The time it was unavailable was from a trip to Hot Standby followed by an electrical shutdown (ESD). The fuel cell's performance is summarized in Table 2 and Table 3. Table 2 is for natural gas and Table 3 is for digester gas.

Table 2 - Fuel Cell Operational Summary on Natural Gas (October 1 – December 31, 2004)

Year	**2004**		**2005**				**2006**	
Parameter	**Q2 andQ3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**
Run time (hours)	1,897	970						
Power generated (kWh)	1.4M	593,000						
Availability	93%	100%						
Shutdown	7%	0%						
Efficiency*	43%	43%						

*Efficiency Measurement 1 from Table 1

Table 3 - Fuel Cell Operational Summary on Digester Gas (October 1 – December 31, 2004)

Year	**2004**		**2005**				**2006**	
Parameter	**Q2 andQ3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**

Year	2004		2005				2006	
Run time (hours)	313	490						
Power generated (kWh)	78,664	357,000						
Availability	64%	94.5%						
Shutdown	35%	5.5%						
Efficiency**	44%	44%						

**Efficiency Measurement 2 from Table 1

Performance of Power Plant Components

This section describes the performance of each of the individual components in the fuel cell power plant.

King County Scrubbed Digester Gas Treatment System (Gas 1)

During the previous quarter (Q3-04), plans were made to change the logic of the fuel cell to allow for switching of fuels at full power. This was in response to the fact that at times the Binax gas scrubbing system produces natural gas that does not meet the PSE pressure specifications, also known as a "divert." Occasionally the scrubbed gas pressure goes up to 260 pounds per square inch (psi), probably when the Binax compressors ramp up a little too quickly after a change in the gas pressure. The do not have variable speed drives. The pressure could change rapidly for a number of reasons. For example, momentary high pressure in the scrubbed gas line could happen when the boiler trips off line, when the fuel cell goes to minimum flow, or when a Binax compressor trips. There are two Binax compressors, stream 1 and stream 2. Currently the fuel cell control system gets a signal when either stream 1 or 2 is diverted, or when there is a final divert. An individual stream divert occurs when a stream that has been out of service for a while and first starts up. With the boiler on, the gas scrubbing system is on the verge of operating only one stream. If the fuel cell is also on consistently, then only one stream is required, which saves power costs of running only one Binax compressor instead of two.

Any divert causes the natural gas produced by the Binax scrubbers to be diverted back to the anaerobic digester gas (ADG) header and subsequently, when a sufficient pressure in the header has been reached, the gas goes to the flares. The divert events cause the methane content of the unscrubbed digester gas to increase abruptly as the scrubbed gas is recycled back and mixed with the unscrubbed gas in the ADG header. This rapid increase is not easily accommodated by the fuel cell. Logic changes were completed in this quarter (Q4-04) to allow the fuel cell to switch to gas 1 or 2 when the variation in gas 3's methane is more than 4% per hour.

The next challenge is to determine how to switch back from gas 3 to gas 1 after a divert. Occasionally a flare was turned on to try to stabilize the methane content in the ADG header by flushing out the line between the scrubber and the flares. Gas appears to separate in the digester gas lines to the flare and the fuel cell. Carbon dioxide appears to concentrate in the low spots and perhaps methane at the higher spots, such as the part of the line closer to the fuel cell. Some experimenting has occurred to maintain a minimum flow of digester gas during the fuel switch from gas 3 to gas 1.

Natural Gas Treatment System (Gas 2)

During the previous quarter, plans were underway to modify the gas 1 natural gas treatment system to allow for removal of COS that is in Gas 2. Construction of the COS removal system was near completion at the end of the quarter.

Digester Gas Treatment System (Gas 3)

The digester gas treatment system removed the target contaminants during Q4-04. In addition to being removed from service for its required quarterly internal inspection, it was also shutdown on two occasions to troubleshoot and repair the lubrication system. There are a series of 8 cam-driven lubricating oilers that provide oil to the digester gas compressor. Two of these failed to provide lubrication periodically. This problem did not occur until late December and was ultimately corrected in January by modifying the system to provide for more oil level in the oil sump from which the oilers draw their suction.

Fuel Cell Stack

No problems have been recorded with the fuel cell stack.

Heat Recovery System

The heat recovery system was not in operation.

Mechanical Balance of Plant (MBOP)

A flange leak in the piping prior to the pre-converter was discovered just prior to the shutdown in September. The leak allowed oxygen to enter the pre-converter, oxidizing the catalyst. Due to the extent of the oxidation, the preconverter and catalyst needed to be replaced prior to restarting the plant after the September shutdown.

Electrical Balance of Plant (EBOP)

No problems were recorded with the EBOP.

Maintenance Items

All normal preventative maintenance tasks were completed in the fourth quarter.
The major corrective maintenance required was related to correcting the deoxidizer flange leak, which resulted in an automatic plant shutdown on September 13 .The deoxidizer repair involved working with the deoxidizer manufacturer to identify a more robust gasket and proper torque values. During the cooldown, the cooldown lineup combined with the deoxidizer leak resulted in a flow path for air from the anode gas oxidizer back through the fuel cell anode side, the superheater, the preconverter and out to atmosphere at the deoxidizer. Because the preconverter catalyst was hot the catalyst was oxidized as a nitrogen blanket could not be maintained. This led to the need to replace the preconverter and its catalyst prior to restart. These repairs resulted in a two week delay to restart after power was restored to the fuel cell power plant.

Performance Metrics

Seventeen performance metrics were established with King County and FuelCell Energy. They are described below in Table 4, with the results from Q4-04.

Table 4 – Performance Goals and Metrics

Performance Goal	Metric	Q4-04 Result
1. Deliver high quality and quantity gas to the fuel cell	Acceptable gas supply >95% of the time. Digester gas BTU content between 550 and 610 BTU/scf @ 4 to 7 in w.c.; 50 to 100°F	Natural gas (NG) quality and quantity acceptable. Digester gas (DG)BTU/methane content at times too high due to divert events returning NG to ADG header.
2. Produce energy as designed on natural gas and digester gas	Produce 15,000 MWhrs gross power for 2-year test period. Prorate to later half of test after plant normalized after first 6-9 months. 1 MW net. Parasitic electric loads for natural gas and digester gas to be measured during testing. Full power = 140 scfm natural gas	2,429 MWhrs after first 6 months of installation (6/14/04 to 12/31/04) 1 MW net produced on NG and DG
3. Produce minimal noise and equipment interferences	60 dBA at a distance of 100 feet from fuel cell pad (70 dBA at a distance of 10 feet)	Not tested
4. Produce energy at a minimal cost	0.2 full time equivalents (FTEs) – Operations 0.2 FTEs – Maintenance 0.1 FTEs – Miscellaneous Cost of energy to produce 1 kWh of power < $0.10 (energy off the grid $0.05, but a premium is paid for green power)	Not applicable to first 6 months of plant normalization
5. Produce minimal air emissions – natural gas and digester gas (LSG/ADG[1])	CO < 10 ppmV NOx < 2 ppmV NMHC < 1 ppmV	Not tested this quarter
6. Produce wastewater/drain water with no adverse impacts to the treatment plant	Water treatment system brine Cooling water Condensate	Not tested this quarter
7. Operate fuel cell on a	Downtime for maintenance and	98% overall this

Performance Goal	Metric	Q4-04 Result
continuous basis	troubleshooting limited to 20 hours/week (remain at hot standby condition) Availability of > 80% Run 85% of the time at full net power for 2 years. Determine frequency of downtime and length of time out of service	quarter (100% availability while on natural gas and 94.5% availability while on digester gas).
8. Operate fuel cell efficiently	45.0% efficiency on natural gas 45.0% efficiency on digester gas	43% on natural gas 44% on digester gas
9. Manage system with ease remotely	Monitor and control system through SCADA at the operations building at FCE's office in Danbury, CT	Acceptable
10. Remove hydrogen sulfide effectively from digester gas	Remove hydrogen sulfide to < 10 ppmV on inlet gas	H2S is reduced to non-detectable at outlet of both DG polishers, part of the PM program.
11. Reasonable costs to dispose of solid waste	SulfaTreat system lasts for 0.6 years before replacement Carbon systems (both natural gas and digester gas systems) last for 0.3 years before replacement Fuel cell lasts for 3 years before replacement Preconverter catalyst lasts for 5 years before replacement Oxidizer catalyst lasts for 5 years before replacement Exhaust gas polisher lasts for 5 years before replacement Deoxidizer catalyst lasts for 5 years before replacement Fuel cell not negatively affected by digester gas Deactivated catalysts (from preconverter, oxidizer, deoxidizer and exhaust gas polisher) (recover precious metals) Fuel cell stack	Not applicable to first 6 months of plant normalization
12. Recover heat successfully	Recover 1.4M Btu /hr of heat (13,800 lbs gas/hr) 650°F out of stack	Heat recovery not in operation this quarter

Performance Goal	Metric	Q4-04 Result
13. Achieve output turndown	25% to 100%	Stable operation demonstrated at power levels ranging form 18% to 100% power on both NG and DG
14. Achieve output ramp rate	0.5 kW/min (cold start)	Complete
15. Meet design service life	10,000 hours (1.15 years)	Approximately 3,600 hours as of 12/31/04
16. Able to restart from a trip	Trip recovery to back on load in approximately 10 hours	Demonstrated on 7/30: approx. 8.5 hours
17. Able to quickly start	Hot start in 10 hours (standby to rated output)	Demonstrated on 8/7 and 8/20: approx. 9 hours each

[1] Digester gas = LSG =ADG = Low pressure sludge gas = anaerobic digester gas

Appendices

A – ENERGY EFFICIENCY AND OUTPUT DATA

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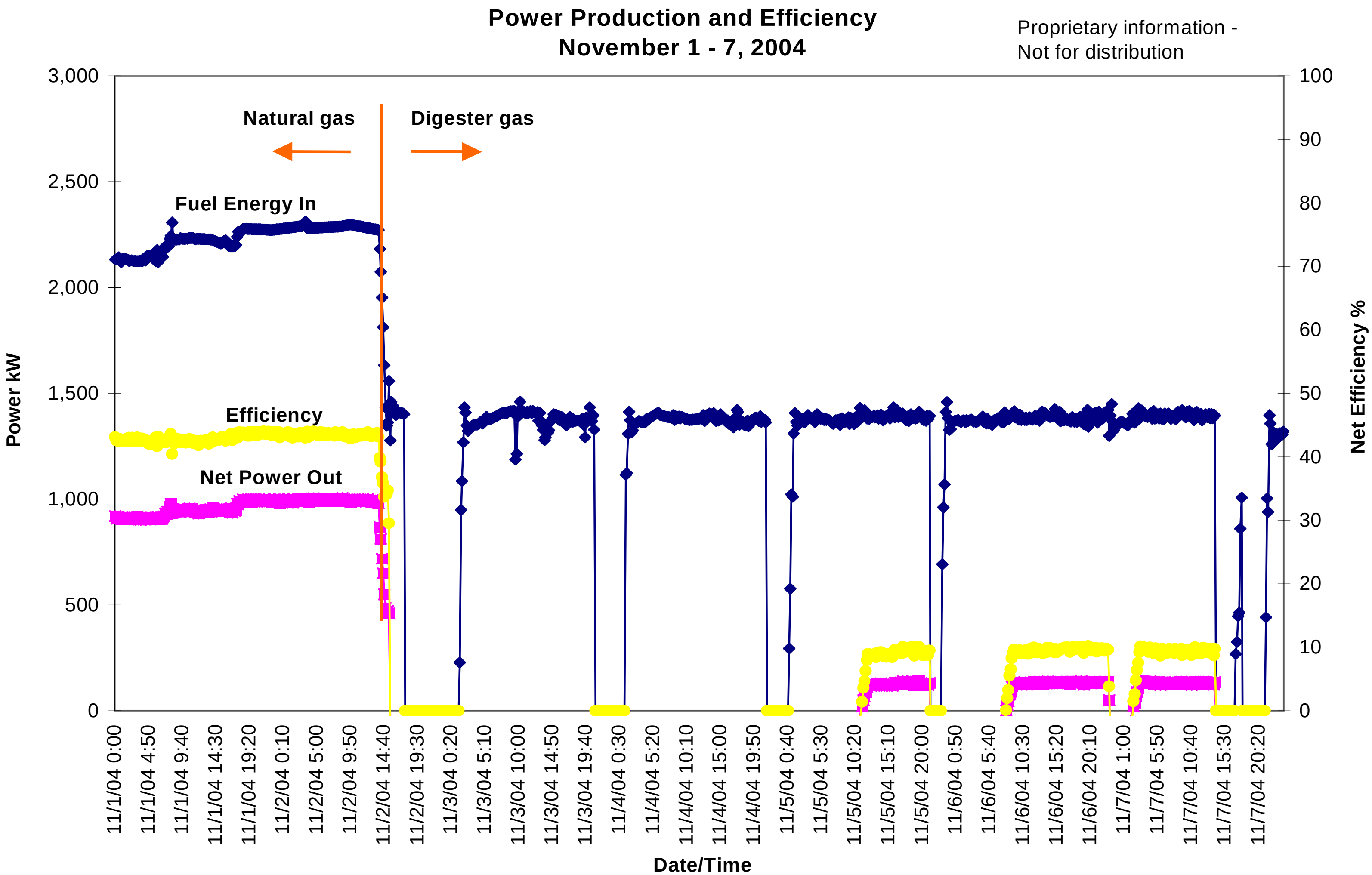
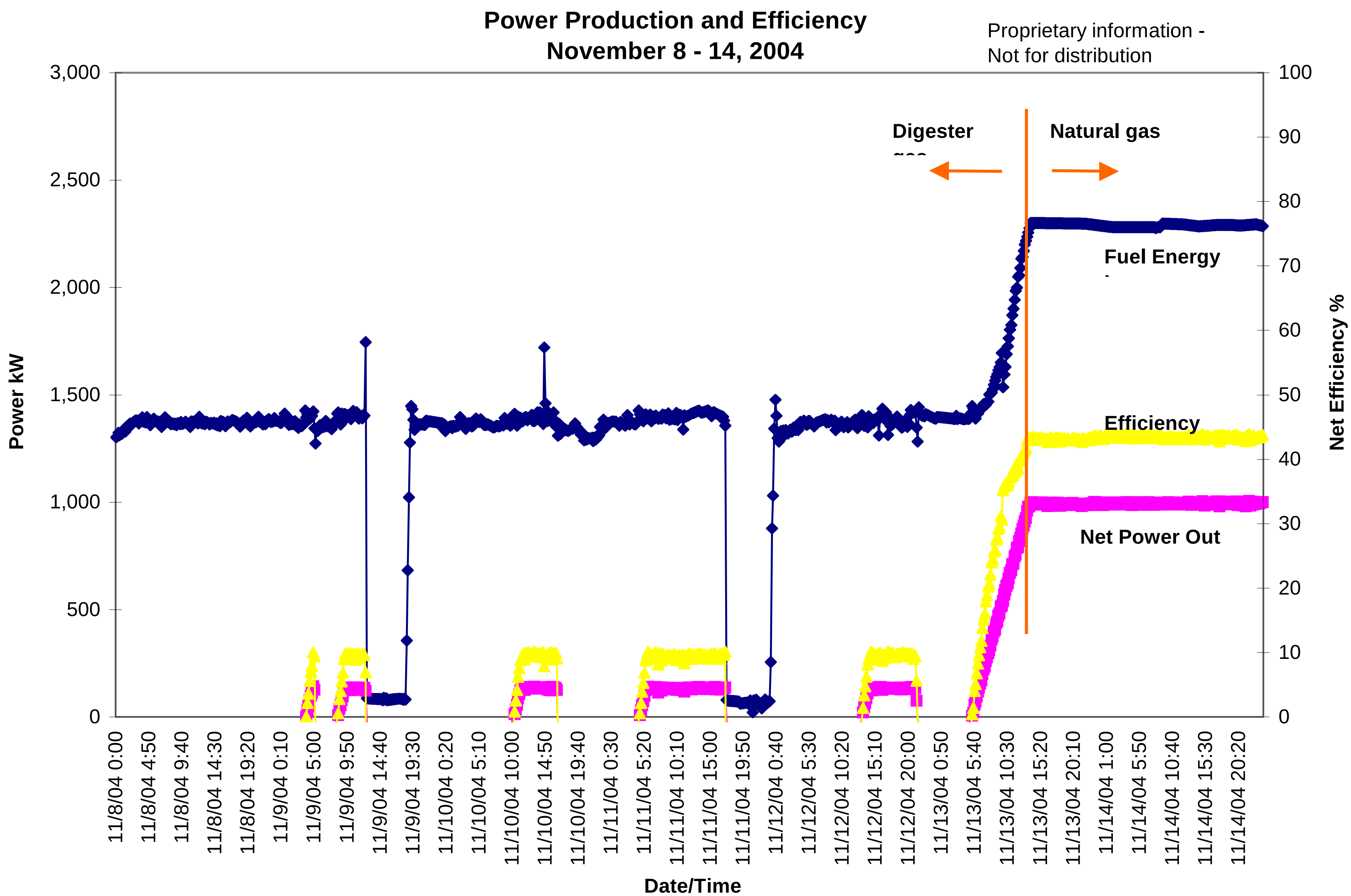


Figure A1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Fuel Energy
Efficiency
Net Power Out
Power kW
Net Efficiency %
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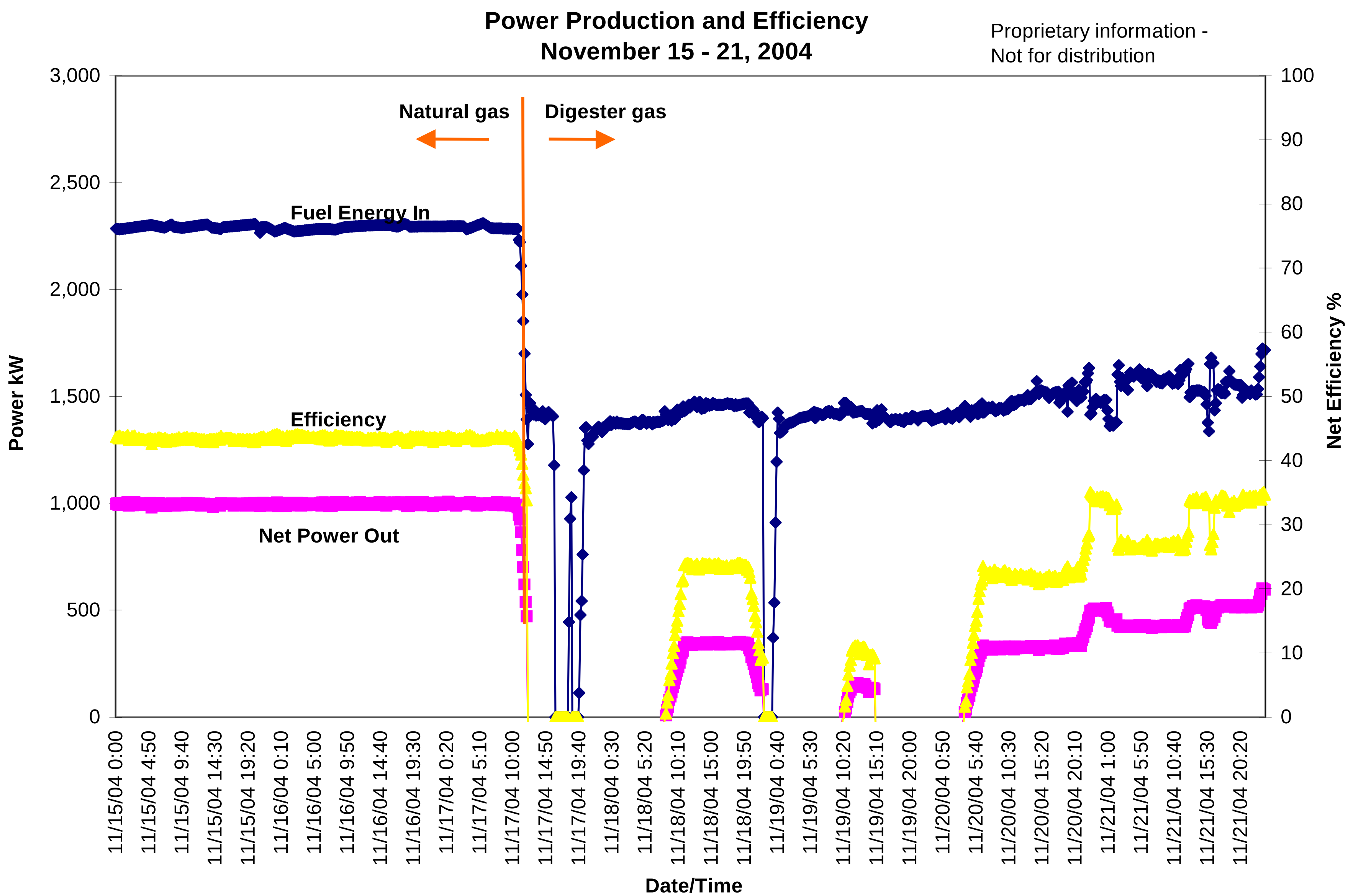
Figure A2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Fuel Energy In
Efficiency
Net Power Out
Power kW
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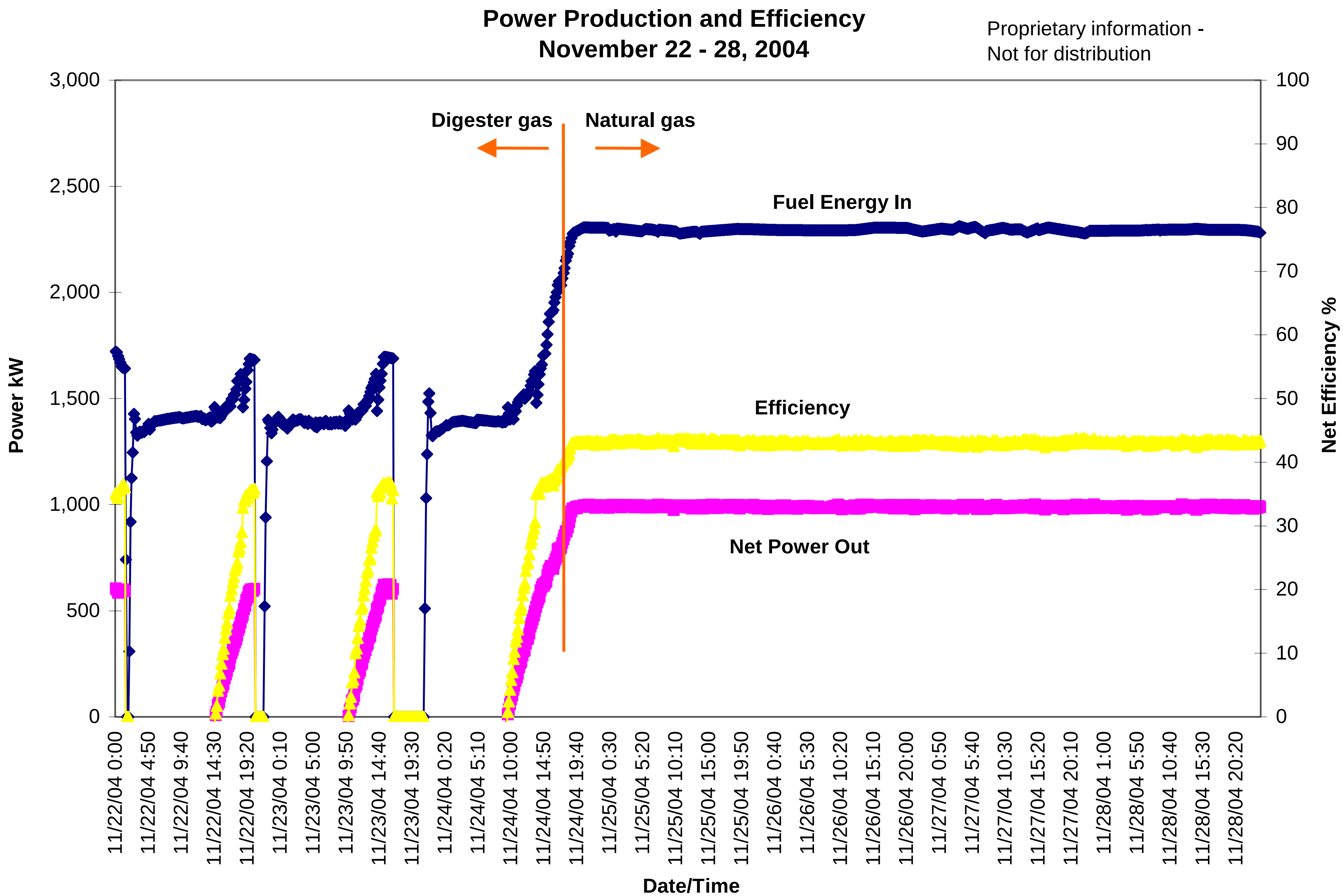
Figure A3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Fuel Energy In
Efficiency
Net Power Out
Power kW
Net Efficiency %
Date/Time
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2,000
1,500
1,000
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0
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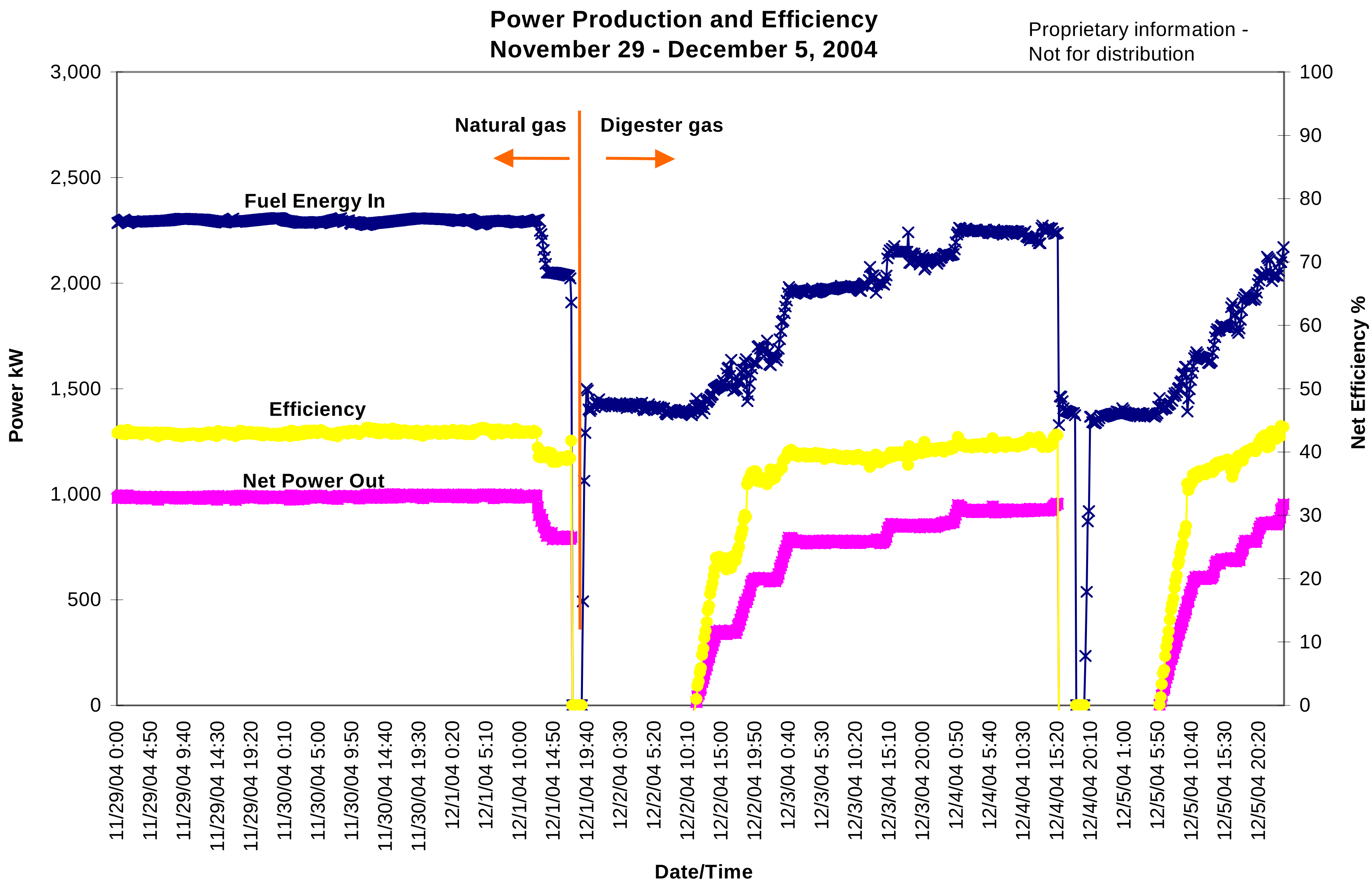
Figure A4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Digester gas
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Efficiency
Net Power Out
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2,000
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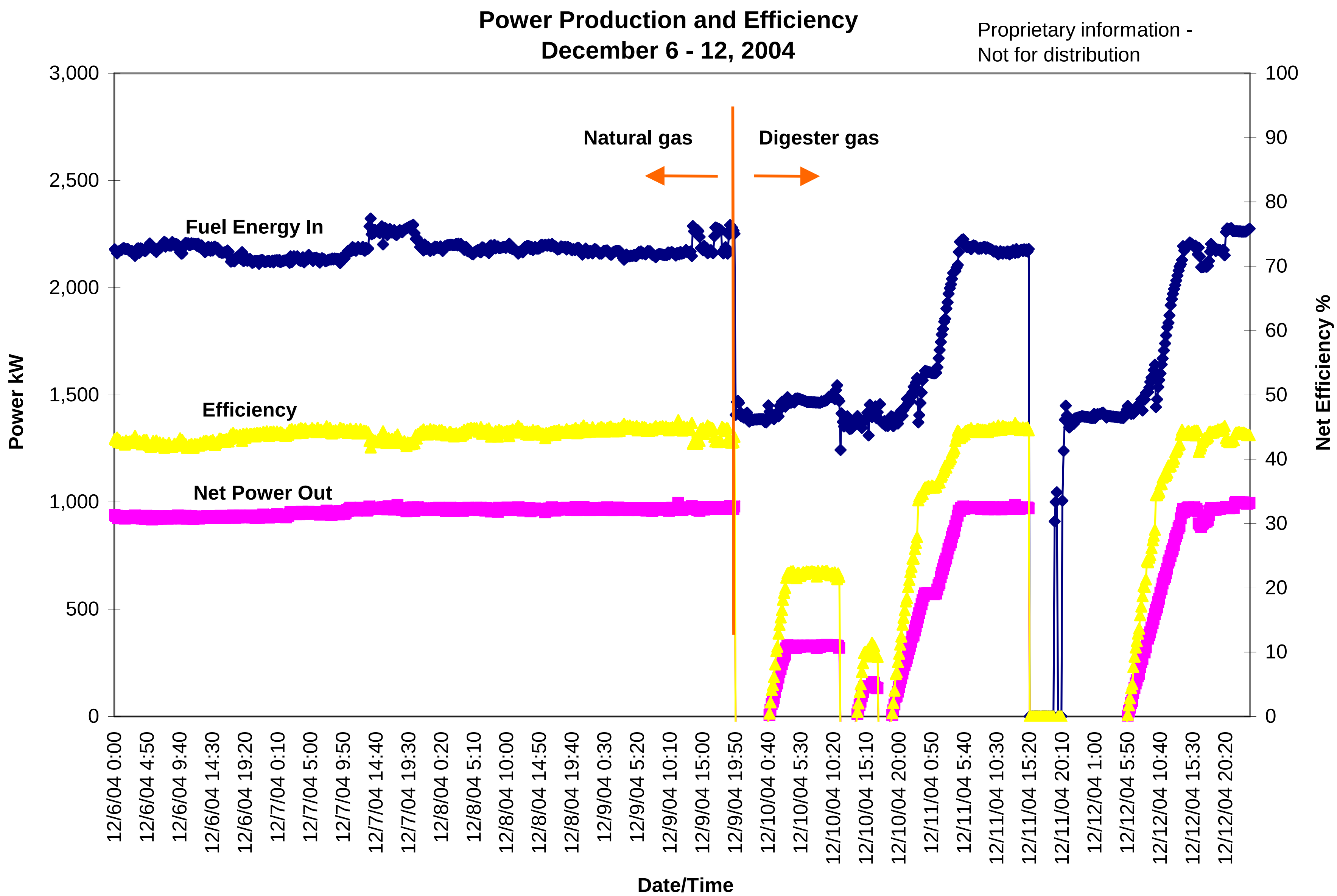
Figure A5


Power Production and Efficiency
December 6 - 12, 2004
Proprietary information -
Not for distribution
Natural gas
Digester gas
Fuel Energy In
Efficiency
Net Power Out
Power kW
Net Efficiency %
3,000
2,500
2,000
1,500
1,000
500
0
100
90
80
70
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Date/Time

Figure A6

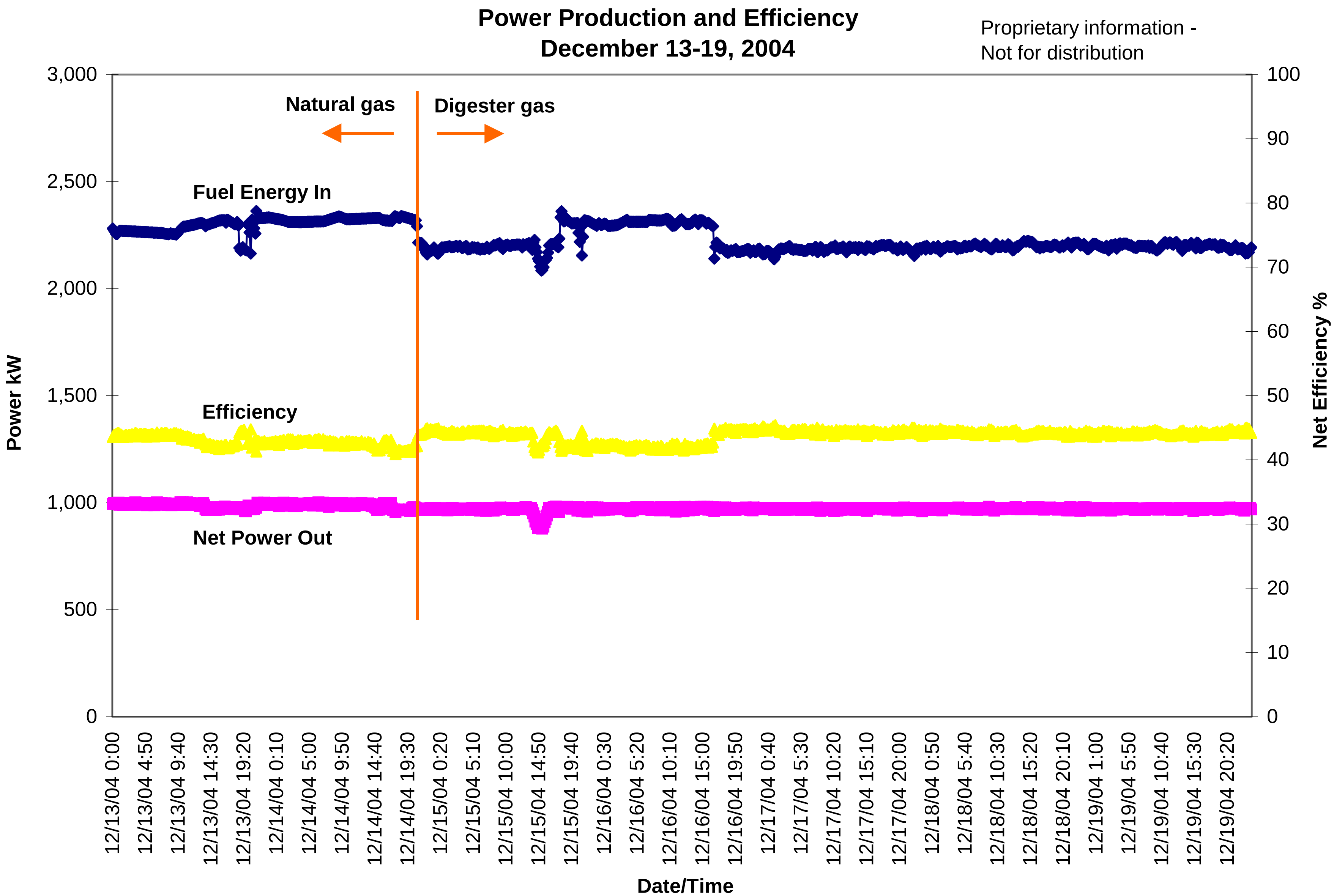

Power Production and Efficiency
December 13-19, 2004
Proprietary information -
Not for distribution
Natural gas
Digester gas
Fuel Energy In
Efficiency
Net Power Out
Power kW
Net Efficiency %
Date/Time
3,000
2,500
2,000
1,500
1,000
500
0
100
90
80
70
60
50
40
30
20
10
0
12/13/04 0:00
12/13/04 4:50
12/13/04 9:40
12/13/04 14:30
12/13/04 19:20
12/14/04 0:10
12/14/04 5:00
12/14/04 9:50
12/14/04 14:40
12/14/04 19:30
12/15/04 0:20
12/15/04 5:10
12/15/04 10:00
12/15/04 14:50
12/15/04 19:40
12/16/04 0:30
12/16/04 5:20
12/16/04 10:10
12/16/04 15:00
12/16/04 19:50
12/17/04 0:40
12/17/04 5:30
12/17/04 10:20
12/17/04 15:10
12/17/04 20:00
12/18/04 0:50
12/18/04 5:40
12/18/04 10:30
12/18/04 15:20
12/18/04 20:10
12/19/04 1:00
12/19/04 5:50
12/19/04 10:40
12/19/04 15:30
12/19/04 20:20

Figure A7

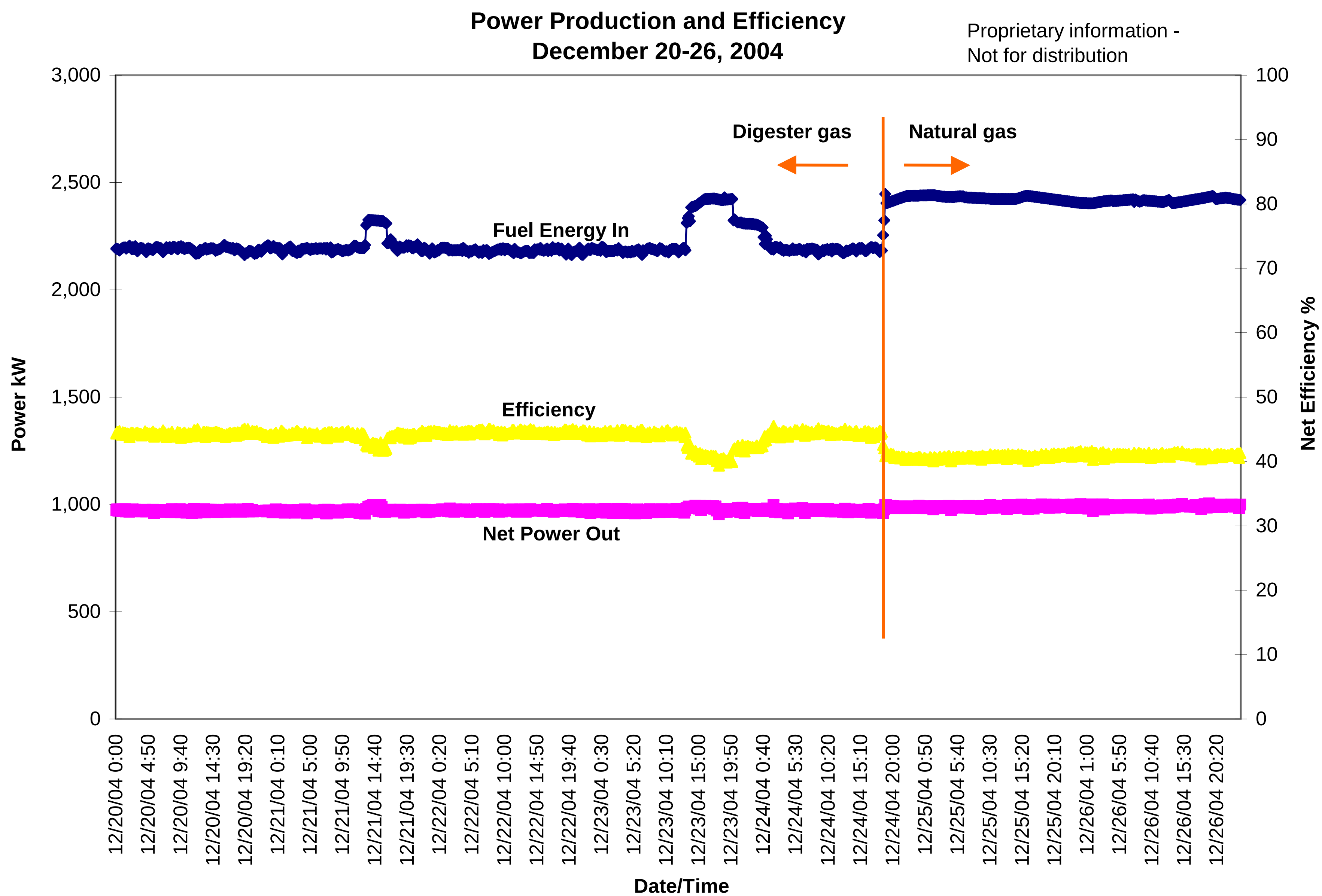
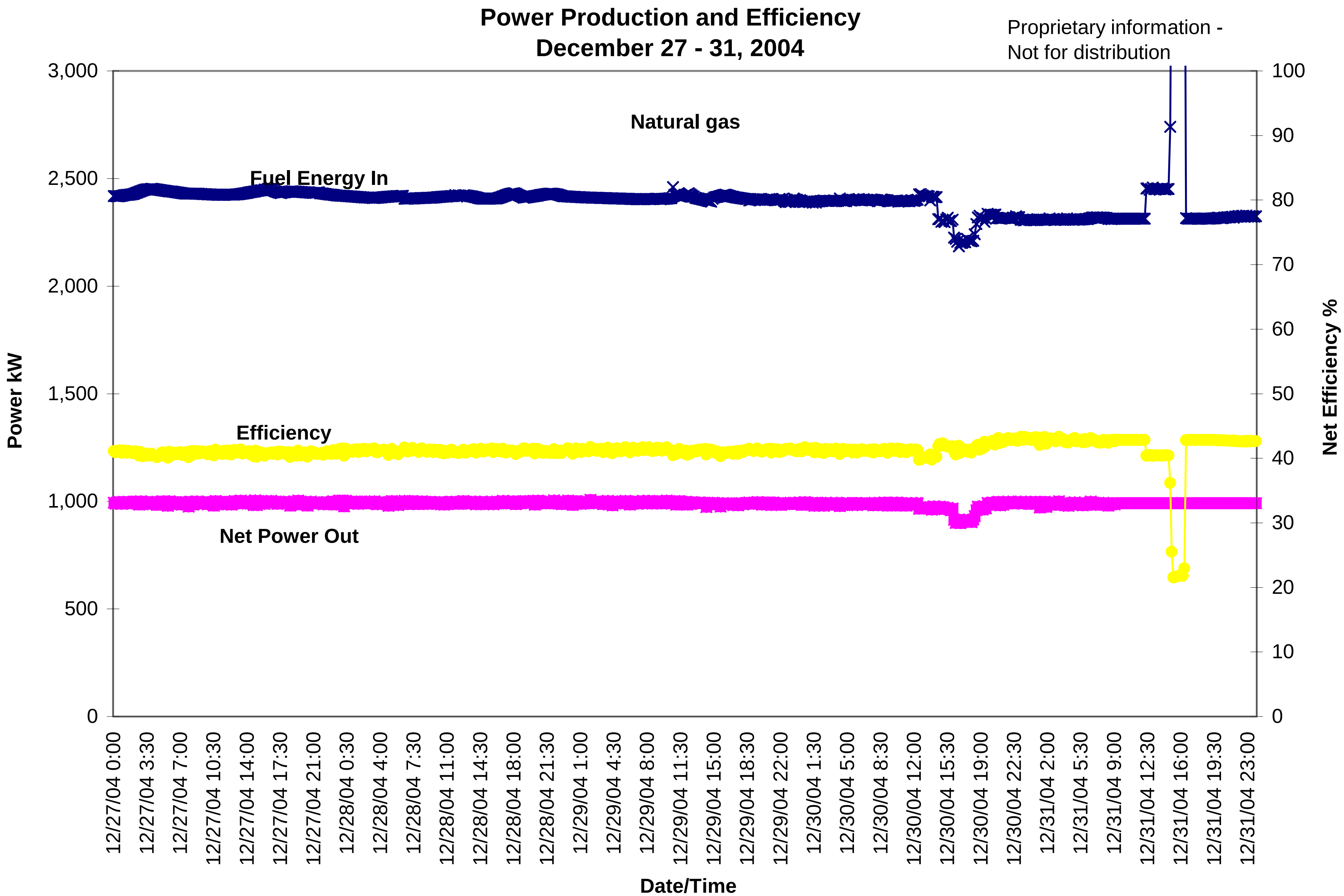

Power Production and Efficiency
December 20-26, 2004
Proprietary information -
Not for distribution
Digester gas
Natural gas
Fuel Energy In
Efficiency
Net Power Out
Power kW
Net Efficiency %
Date/Time
3,000
2,500
2,000
1,500
1,000
500
0
100
90
80
70
60
50
40
30
20
10
0
12/20/04 0:00
12/20/04 4:50
12/20/04 9:40
12/20/04 14:30
12/20/04 19:20
12/21/04 0:10
12/21/04 5:00
12/21/04 9:50
12/21/04 14:40
12/21/04 19:30
12/22/04 0:20
12/22/04 5:10
12/22/04 10:00
12/22/04 14:50
12/22/04 19:40
12/23/04 0:30
12/23/04 5:20
12/23/04 10:10
12/23/04 15:00
12/23/04 19:50
12/24/04 0:40
12/24/04 5:30
12/24/04 10:20
12/24/04 15:10
12/24/04 20:00
12/25/04 0:50
12/25/04 5:40
12/25/04 10:30
12/25/04 15:20
12/25/04 20:10
12/26/04 1:00
12/26/04 5:50
12/26/04 10:40
12/26/04 15:30
12/26/04 20:20

Figure A8



Power Production and Efficiency
December 27 - 31, 2004
Proprietary information -
Not for distribution
Natural gas
Fuel Energy In
Efficiency
Net Power Out
Power kW
Net Efficiency %
Date/Time
3,000
2,500
2,000
1,500
1,000
500
0
100
90
80
70
60
50
40
30
20
10
0
12/27/04 0:00
12/27/04 3:30
12/27/04 7:00
12/27/04 10:30
12/27/04 14:00
12/27/04 17:30
12/27/04 21:00
12/28/04 0:30
12/28/04 4:00
12/28/04 7:30
12/28/04 11:00
12/28/04 14:30
12/28/04 18:00
12/28/04 21:30
12/29/04 1:00
12/29/04 4:30
12/29/04 8:00
12/29/04 11:30
12/29/04 15:00
12/29/04 18:30
12/29/04 22:00
12/30/04 1:30
12/30/04 5:00
12/30/04 8:30
12/30/04 12:00
12/30/04 15:30
12/30/04 19:00
12/30/04 22:30
12/31/04 2:00
12/31/04 5:30
12/31/04 9:00
12/31/04 12:30
12/31/04 16:00
12/31/04 19:30
12/31/04 23:00

Figure A9